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A study of topological vertexing for heavy quark tagging*

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Abstract

We compare heavy quark tagging and anti-tagging efficiencies for vertex detectors with different inner raddi using the topological vertex technique developed at the SLC/SLD experiment. Charm tagging benefits by going to very small inner radii.

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1 Introduction

A vertex detector (VTX) is a very poweful particle identification device for the future linear collider experiment. VTX allows not only b/c-jet tagging but also anti-b/c jet tagging. Excellent b/c-jet tagging is required in studies of Higgs and Top physics. VTX performance depends critically on the innermost radius (r_{inner}) of the detector. Many studies have been done to achieve smaller r_{inner} in order to get better impact parameter resolution. Current allowable r_{inner} is expected to be ~ 1 cm. However a VTX configuration with $r_{inner} = 1$ cm is very difficult to achieve and there are presently no physics studies comparing such aggressive designs with more conservative ones. In this paper, we discuss the physics-performance difference between $r_{inner} = 1$ cm and 2 cm VTX configurations, using the topological vertexing technique developed at the SLC/SLD experiment.

2 Tools

We use the LCD fast simulation and a topological vertexing and a mass tag technique for the study.

The LCD fast simulation [1] is based on the ROOT analysis tool [2] and the C++ programming language to maximally benefit from object oriented programming techniques. In this simulation, track particles are smeared according to their error matrices. The error matrices are given by a look-up table method based on momentum and $\cos\theta$ of charged particles. The error matrices include off-diagonal elements to give added realism. The vertex detector is assumed to have layers at several radii ($r = 2.4$ cm, 3.6 cm, 4.8 cm, 6.0 cm) and resolution of 5 μm for each layer in both detector configuration. The VTX configuration with $r_{inner} = 1$ cm has an extra layer of $r = 1.2$ cm with resolution of 5 μm.

The success of the CCD-based VTX at the SLC/SLD experiment [3, 4] argues strongly that a CCD-based VTX will provide optimal performance in a future linear collider experiment. Taking advantage of the precise 3-D spatial points provided by the VTX, a topological vertexing technique [5] has been developed. The topological vertexing naturally associates tracks with the vertices where they originated and can reconstruct a full b/c-meson decay chain, i.e, primary, secondary, and tertiary vertices. Using the reconstructed secondary/tertiary vertex, the invariant mass of the tracks associated with decay is used to identify jet flavor (mass tag technique [6]). This combination of the techniques gives the best heavy-flavor-jet tagging performance in e^+e^- colliding experiments at present. Here it should be noted that the secondary/tertiary vertex reconstruction enables vertex charge information to be determined which gives quark/anti-quark jet identification even for neutral B's [7]. The original vertexing program, called ZVTOP, was written in Prepmort programing language; we translated the code into the C++ language in order to suit the environment of the LCD fast simulation more naturally. Other physics studies which use the program are reported in these proceedings[8, 9].

Table 1: The performance of two different VTX configurations.

	$r_{inner} = 1$ cm	$r_{inner} = 2$ cm
impact parameter resolution	$3.2\mu\mathrm{m} \bigoplus 8.5\mu\mathrm{m}/p\sin^{2/3}$	$3.5\mu\mathrm{m} \bigoplus 14\mu\mathrm{m}/p\sin^{2/3}$
reconstructed primary vertex resolution	$4.6\mu\mathrm{m}(xy)$ $3.7\mu\mathrm{m}(rz)$	$6.9\mu\mathrm{m}(xy)$ $5.2\mu\mathrm{m}(rz)$
b-jet tagging efficiency and purity	$\epsilon = 63\%$ $\Pi = 97\%$	$\epsilon = 62\%$ $\Pi = 97\%$
c-jet tagging efficiency and purity	$\epsilon = 32\%$ $\Pi = 83\%$	$\epsilon = 27\%$ $\Pi = 80\%$
anti-b/c jet tagging efficiency and purity	$\epsilon = 81\%$ $\Pi = 91\%$	$\epsilon = 78\%$ $\Pi = 90\%$

3 Performance

In order to investigate the influence of the VTX configuration, we considered the following variables: (1) impact parameter resolution; (2) reconstructed primary vertex resolution; and (3) b-tag, c-tag, and anti-b/c tag efficiencies and purities. These studies are done using hadronic decay events at $\sqrt{s} = 91.26$ GeV. The results are summarized in Table 1.

As we expect, $r_{inner} = 1$ cm VTX configuration shows better impact parameter and reconstructed primary vertex resolutions than $r_{inner} = 2$ cm. The reconstructed primary vertex resolution, in particular rz resolution, is important to heavy quark physics at giga-Z experiment. We also believe that the resolution will play an important role when we try to discriminate mini-jet backgrounds from Higgs signal events [10]. This idea needs further study.

For jet-flavor identification, we see a result contrary to our naive expectation. Figs. 1 and 2 show the purity against total efficiency plots for b-jets and c-jets obtained by varying the cut of vertex invariant mass, respectively. From these figures, we can not see significant differences in b-jet tagging between the two VTX configurations, but we do see significant improvements for c-jet tagging. This can be understood because the maximum b tag efficiency is limited by the fraction of decays which ZVTOP can identify, i.e. those resulting in at least two charged particles. Furthermore, the long b lifetime ensures that most decays are well-separated from the primary; hence improved resolution is not needed to find more decay vertices close to the IP. With improving VTX resolution the c-jet efficiency increases faster than the b-jet efficiency. We need further study to understand this behavior fully.

In the previous section, we mentioned that the importance of secondary/tertiary vertex reconstruction. This is something that has been overheaded in past linear collider studies. For charged b or c hadrons, vertex charge identifies whether its a quark or anti-quark jet. Fig. 3 illustrates the clear charge separation for B^+/B^- decay vertex. According to Ref. [9], we can know the $t/\bar{t}$-quark direction with efficiency and purity of 78 % and 41 %, respectively, by looking at the charge of the B it decays into, requireing $|\cos\theta_{track}| < 0.9$.

4 Summary

We have developed a fast simulation code to optimize the detector design for a future linear collider experiment. First results with a topological vertexing technique are presented in this proceeding. The two VTX configurations ($r_{inner} = 1$ cm and 2 cm) do not show significant

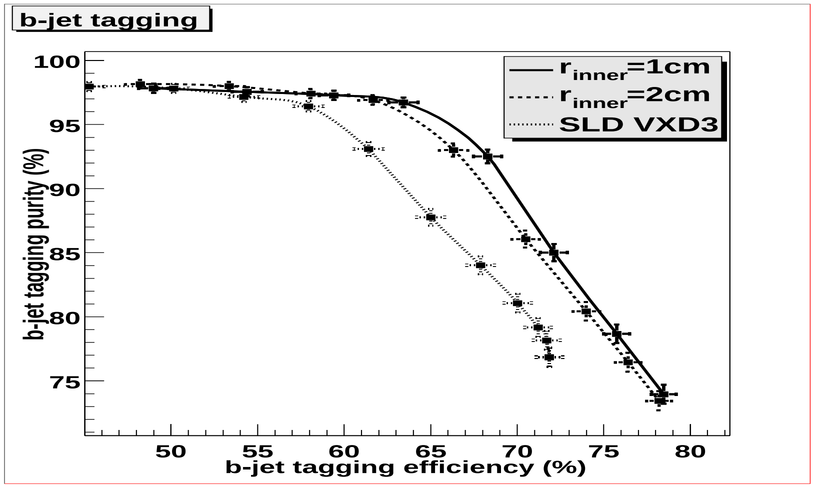

Figure 1: Performance of b-jet flavor tag.

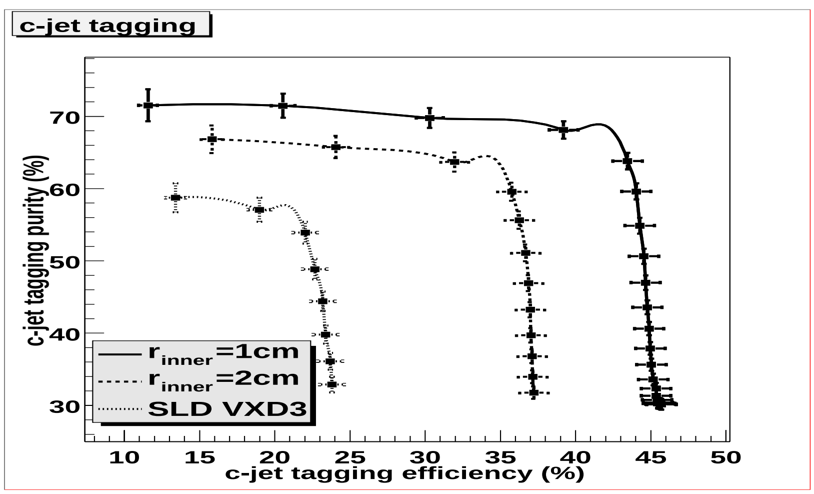

Figure 2: Performance of c-jet flavor tag.

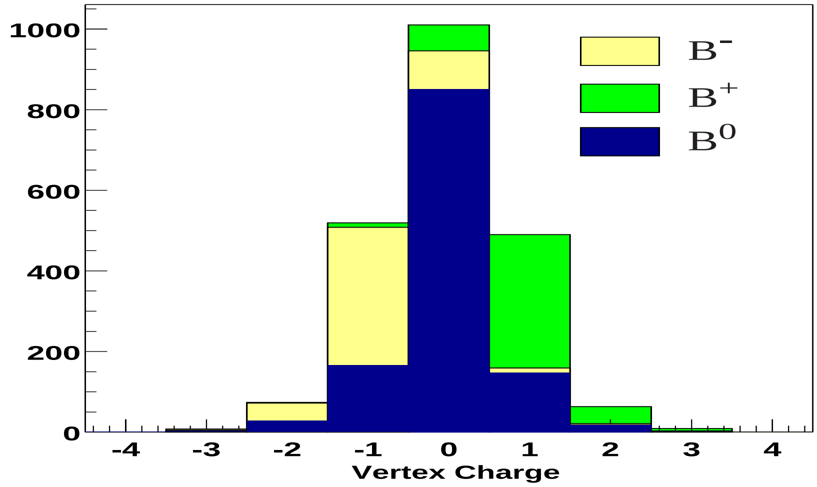

Figure 3: Vertex charge.

difference for b-jet tagging, but do for c-jet tagging. This should be investigated with further study.

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